plug power
FUEL CELL SYSTEMS

Distributed Energy Road Show

-Scott Wilshire, Director of Marketing Engagement--

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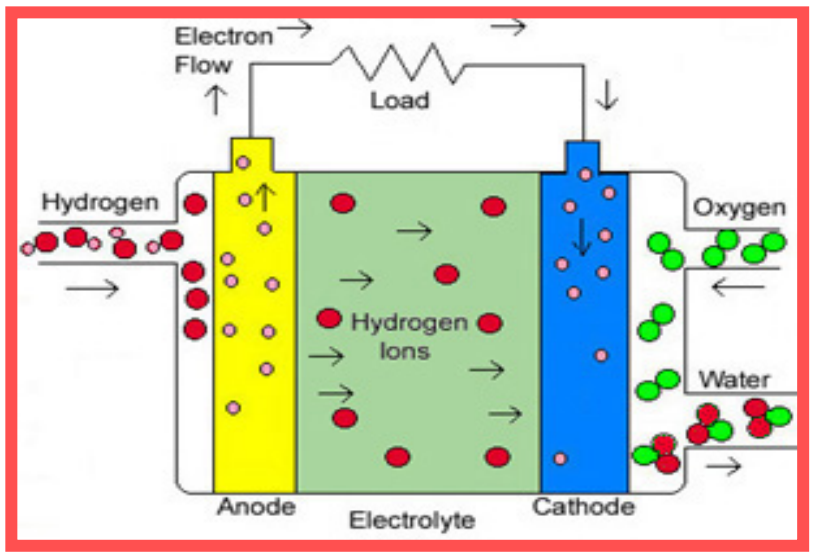
OUTLINE

- What is a Fuel Cell?
  - Types of Fuel Cells
- What is a Fuel Cell System?
  - Fuel Processor
  - Balance of Plant
  - Inverter
- Technology Adoption
- Codes and Standards
  - Product Standards
  - Installation Standards
  - Interconnect Standards
  - Challenges
- System Interfaces
- Questions

FUEL CELL - FUNDAMENTALS

$H_2 + O_2 \rightarrow H_2O$

A fuel cell is a device that generates electricity by electrochemically reacting hydrogen and air.



Every fuel cell has

One positive electrode - cathode

One negative electrode - anode

An electrolyte - carries charged particles

A catalyst - speeds up the reactions to generate electricity

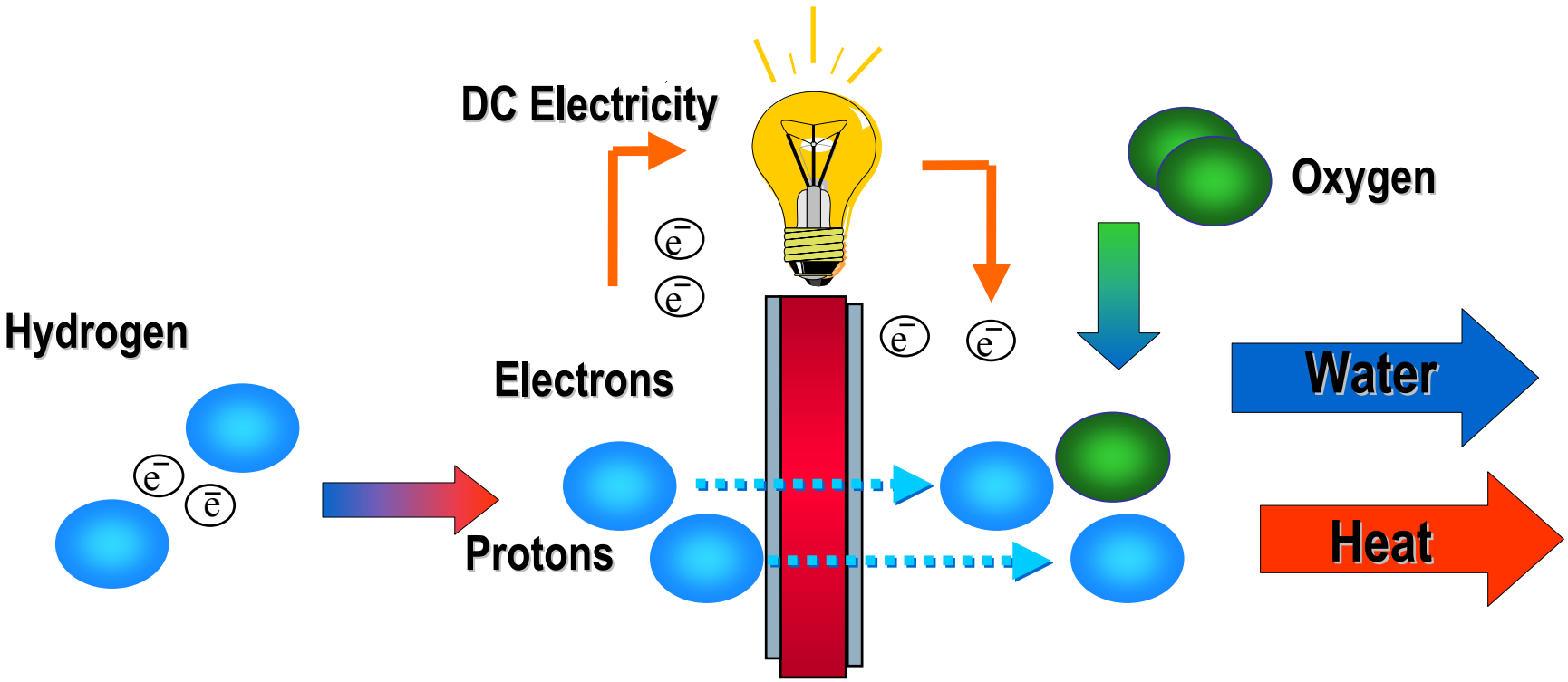
FUEL CELL OPERATING COMPARISONS

Fuel Cell Type	Electrolyte	Ions	Temperature (°C)	Cell Voltage (V)	Size (largest) (kW)
Alkaline	Potassium Hydroxide	OH-	80	0.6 - 0.8	100
PAFC	Phosphoric Acid	H+	200	0.6 - 0.8	670
MCFC	Molten Carbonate	CO_3=	550 - 650	0.7 - 0.85	250
SOFC	Solid Doped Zn-Oxide	O=	850 - 1000	0.6 - 0.75	100
PEMFC	Solid Polymer	H+	100	0.6 - 0.8	250

FUEL CELL OPERATING COMPARISONS

Fuel Cell Type	Current Density (mA/cm^2)	System Efficiency	Fuel Proc. Complexity	Stack Power Density	Transient Capability
Alkaline	60 - 120	35 - 50	Medium	Medium	High
PAFC	100 - 400	35 - 45	Medium	Medium	Medium
MCFC	100 - 200	45 - 55	Low	Low	Low
SOFC	100 - 300	45 - 50	Low	Medium	Low
PEMFC	400 - 900	32 - 40	High	High	High

FUEL CELL PROCESS



$H_2 \Leftrightarrow 2H^+ + 2e^-$

0 Volts

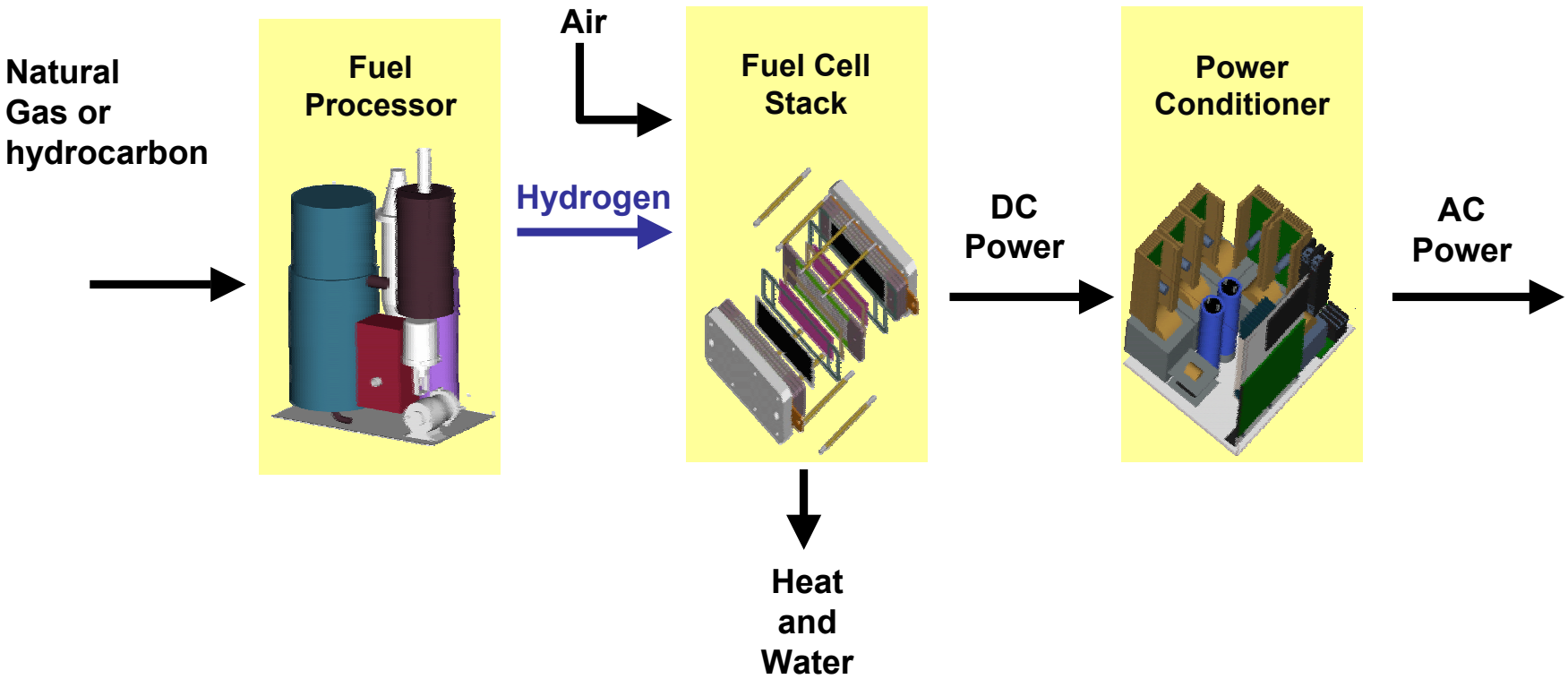
$1/2O_2 + 2e^- \Leftrightarrow 1/2O_2^{--}$

~1.23 Volts

$H_2 + 1/2O_2 \dashrightarrow H_2O$

Approx. 1 volt or less/cell, therefore add cells together

SYSTEM COMPONENTS



INTEGRATED SYSTEM

Fuel

Air

Water

AC Power

Heat

Fuel Processor

Power Generation

Inverter

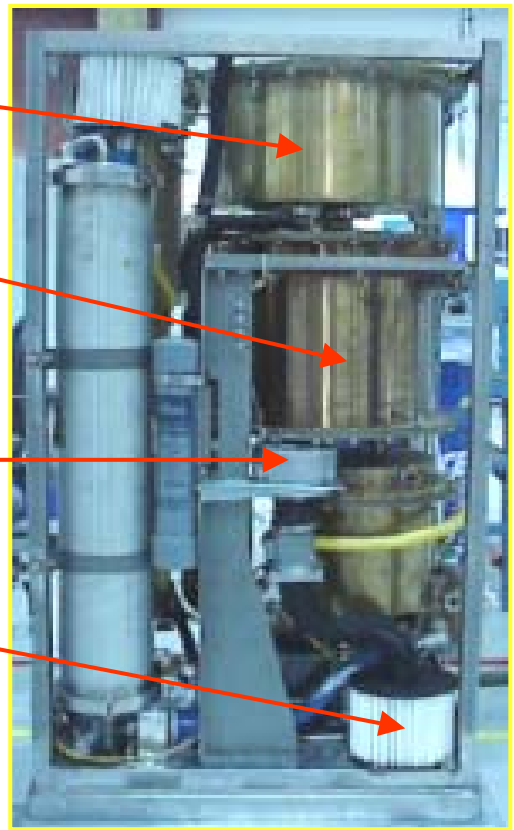
FUEL PROCESSOR

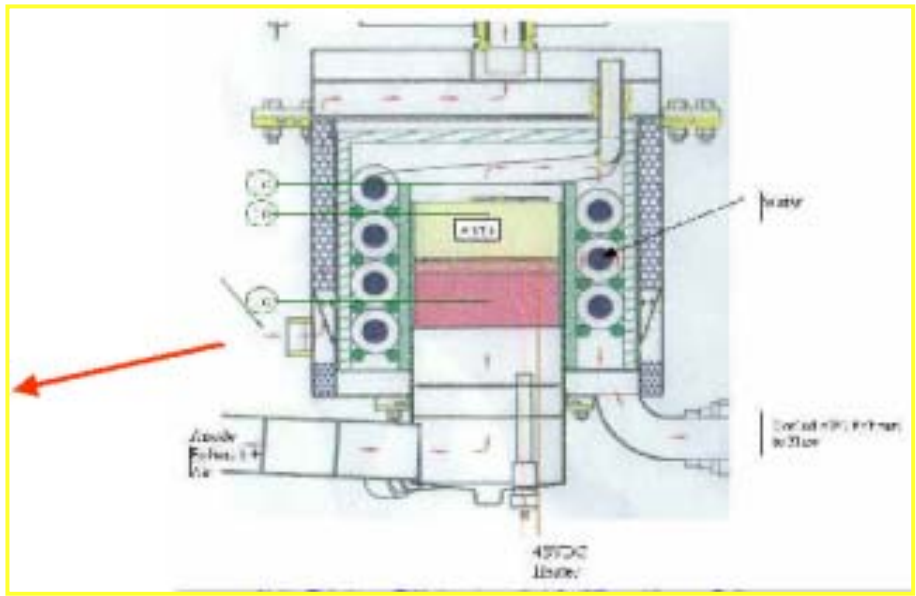
Prox

Main Reactor

ATO Blower

ATO Filter

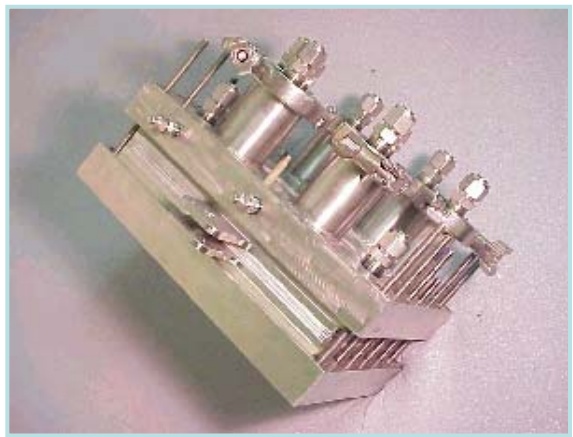




Viewed with Fuel Processing Module Side Panel Removed

POWER GENERATION

Power Generation Module - uses hydrogen in **reformate** to produce electricity (DC voltage)



POWER GENERATION & BALANCE OF PLANT

- Fuel & Air Delivery
- Cooling
- Waste Heat Capture
- Integrated Controls
  - Fuel Processor
  - Stack/Balance of Plant
  - Inverter/Grid

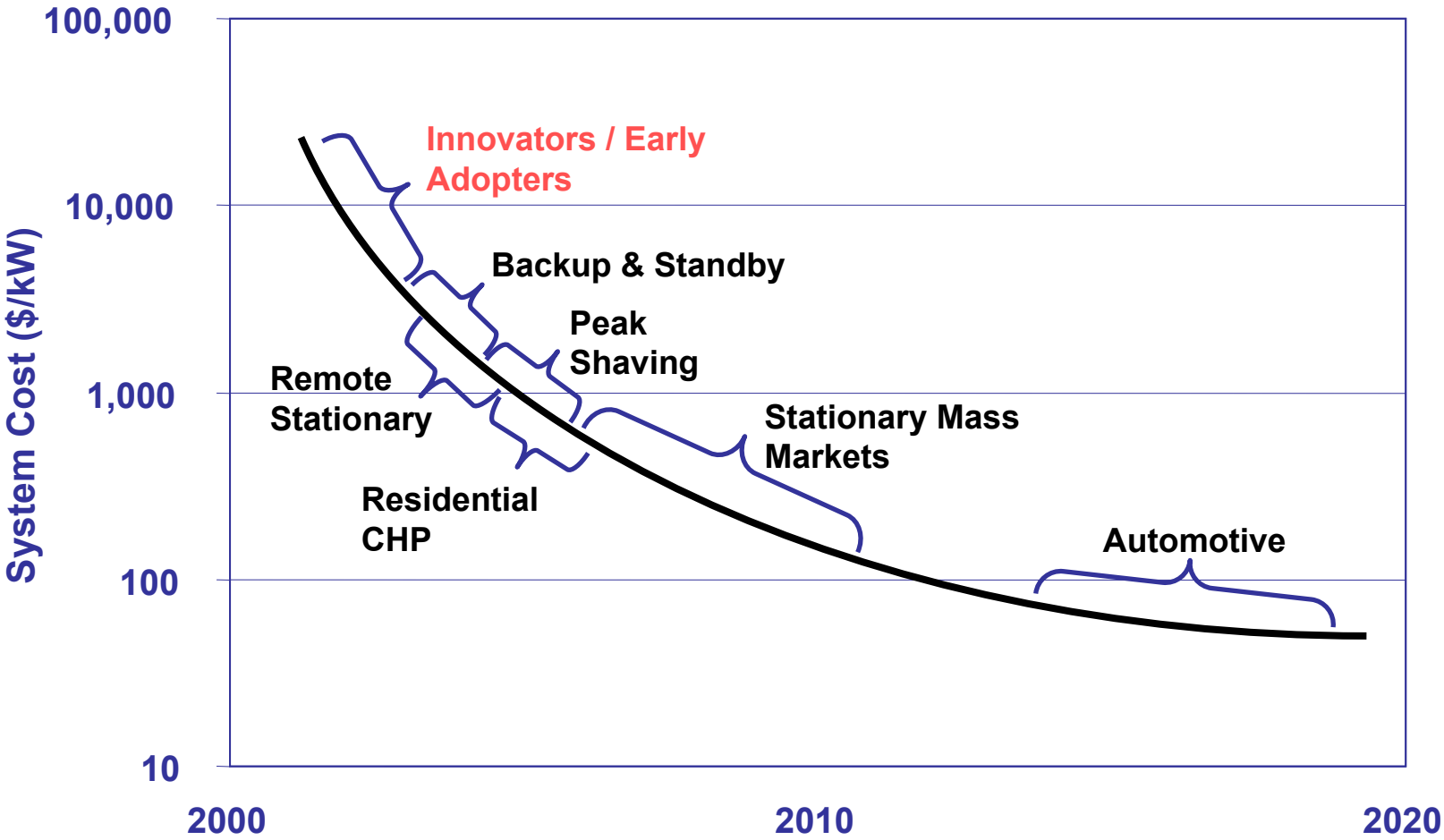
INVERTER

- Convert Stack DC power or Battery DC power to AC power
- Provide Auxiliary power
- Provide isolation between the stack and the AC connection
- Provide control system all electrical statistics including stack voltage and current
- Provide Anti-Islanding capability

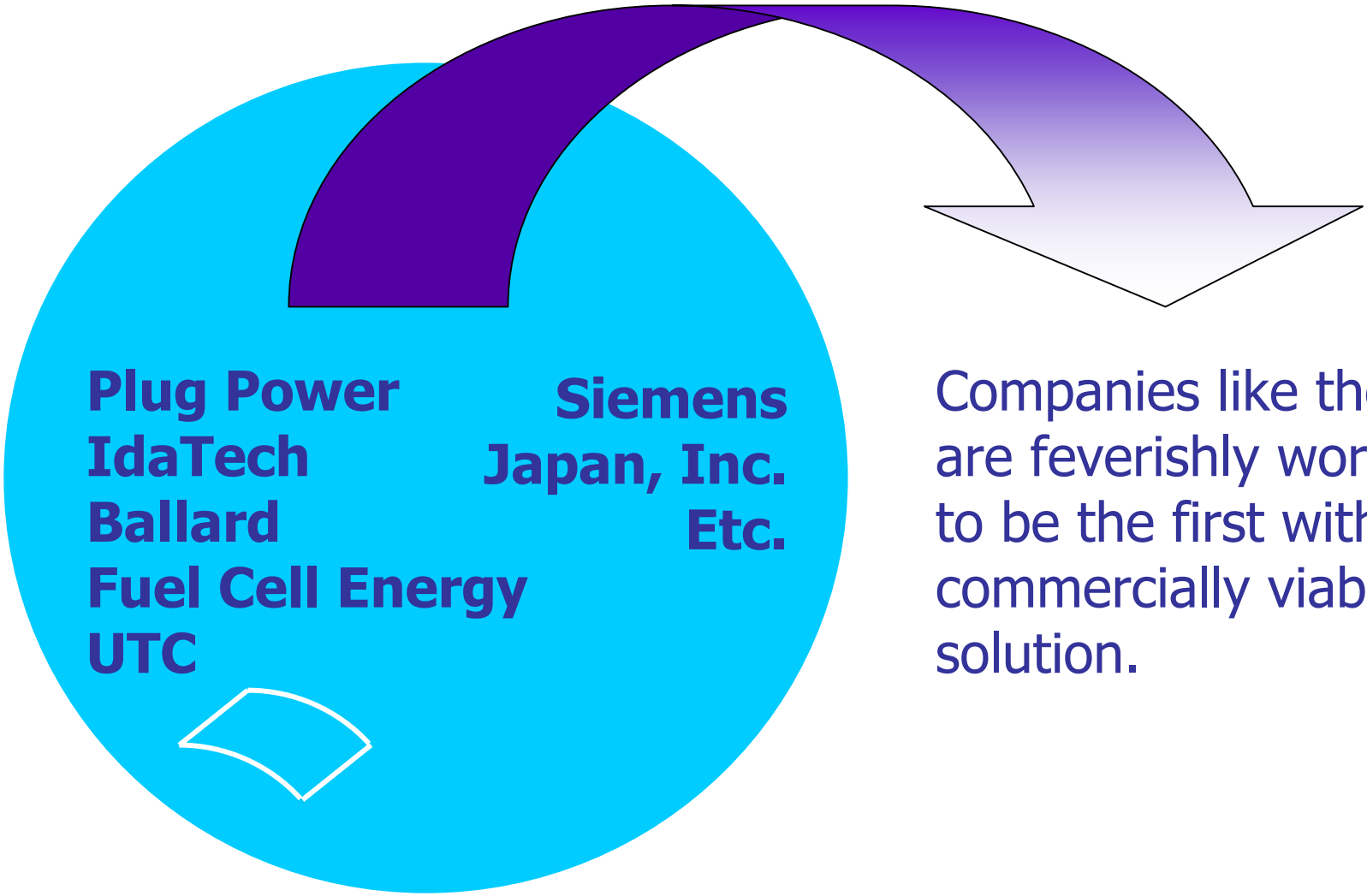
PEM TECHNICAL CHALLENGES

- Fuel Processor
  - Alternate Fuels
  - Energy Storage, Load Following
- Stack
  - Longevity
- Controls
  - Load Following
  - Communications
- Cost

THE FUTURE - INDUSTRY COST CURVE

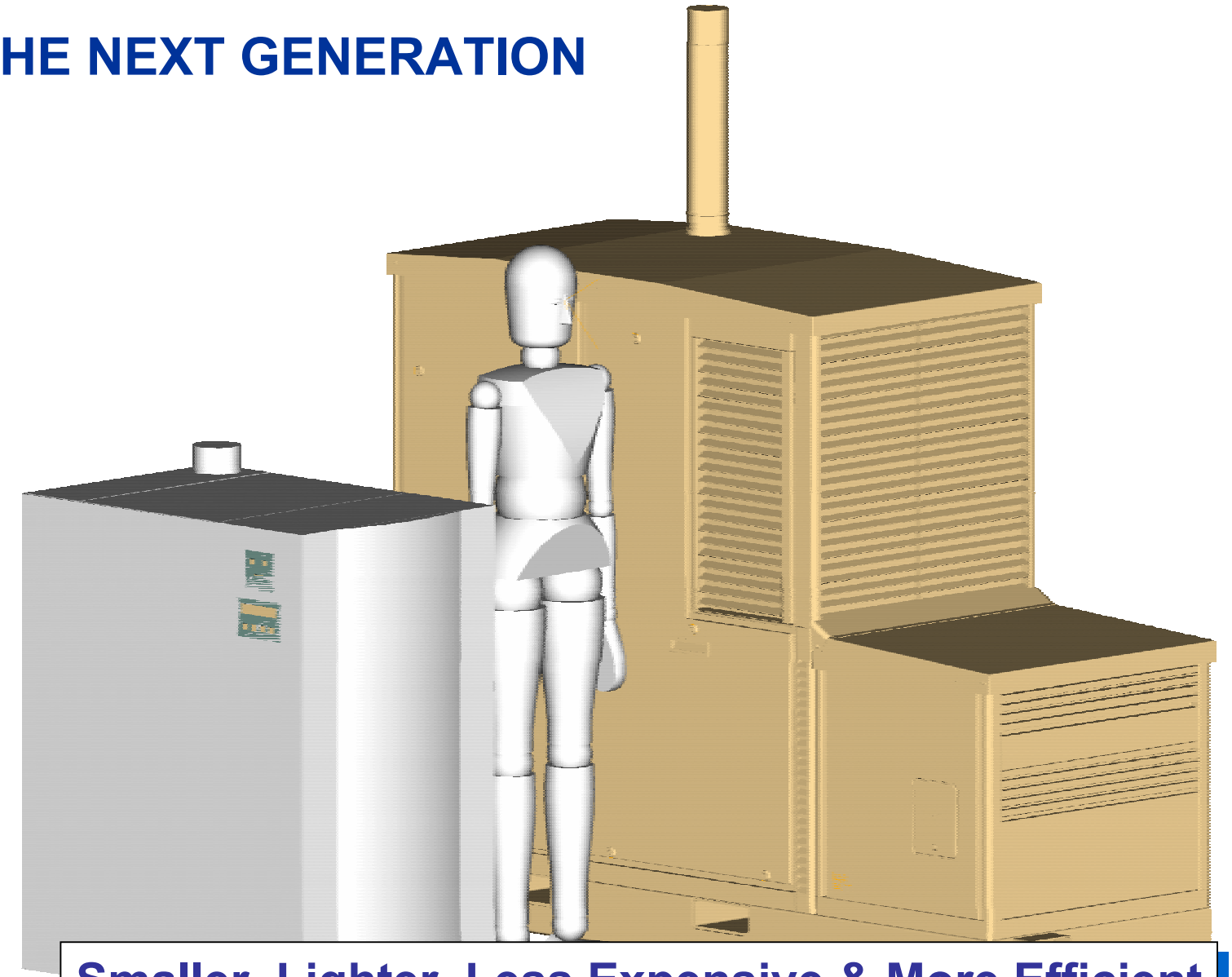


THE INDUSTRY



Companies like these are feverishly working to be the first with a commercially viable solution.

THE NEXT GENERATION

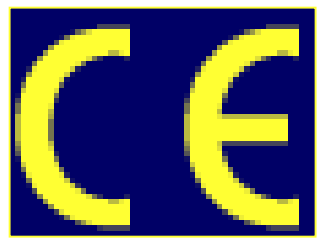


Smaller, Lighter, Less Expensive & More Efficient

PRODUCT STANDARDS

- ANSI Z21.83 - Standard on Fuel Cell Power Plants. Scope includes stationary FCS. Currently addresses natural gas and propane fueled systems.
- ASME Performance Test Code 50 - Fuel Cell Power Systems
- UL 1741 - UL Standard for Safety for Inverters, Converters, and Controllers for Use in Utility Interactive or Standby Systems
- Listing and Certification - For public safety, installations should not be allowed without field verification. Product should display compliance symbols.

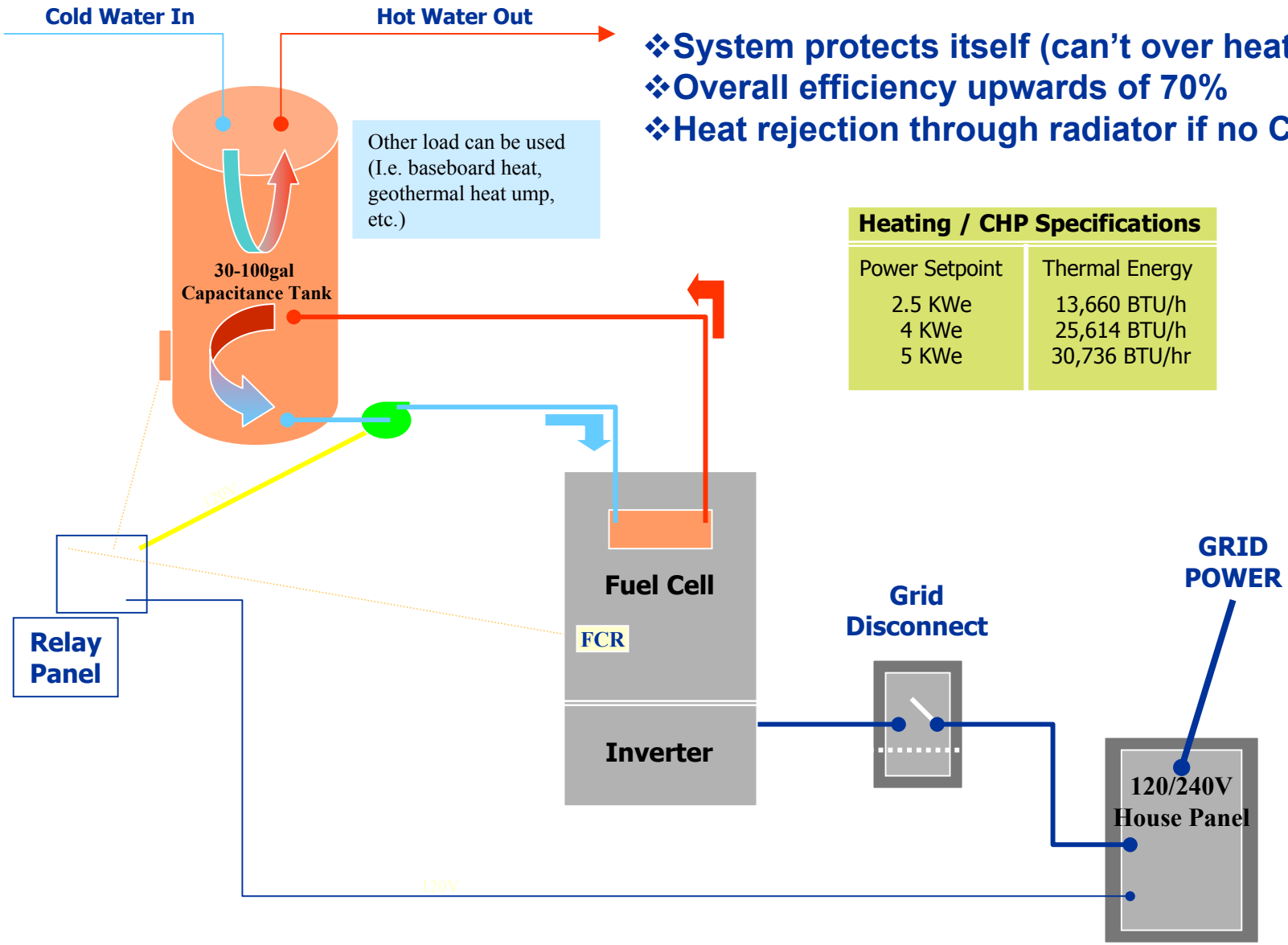




STANDARDS UNDER DEVELOPMENT

- FERC - Federal Standard for Small Generator Interconnection.
- IEEE 1547 - Draft Standard for Interconnecting Distributed Resources with Electric Power Systems.
- ANSI CSA FC 1 - This proposed standard will replace Z21.83 and be broadened to include most types of fuels, gas and liquid, hydrocarbons and alcohols.
- IEC TC105 - International Fuel Cell Standard

INSTALLATION CONFIGURATION - CHP

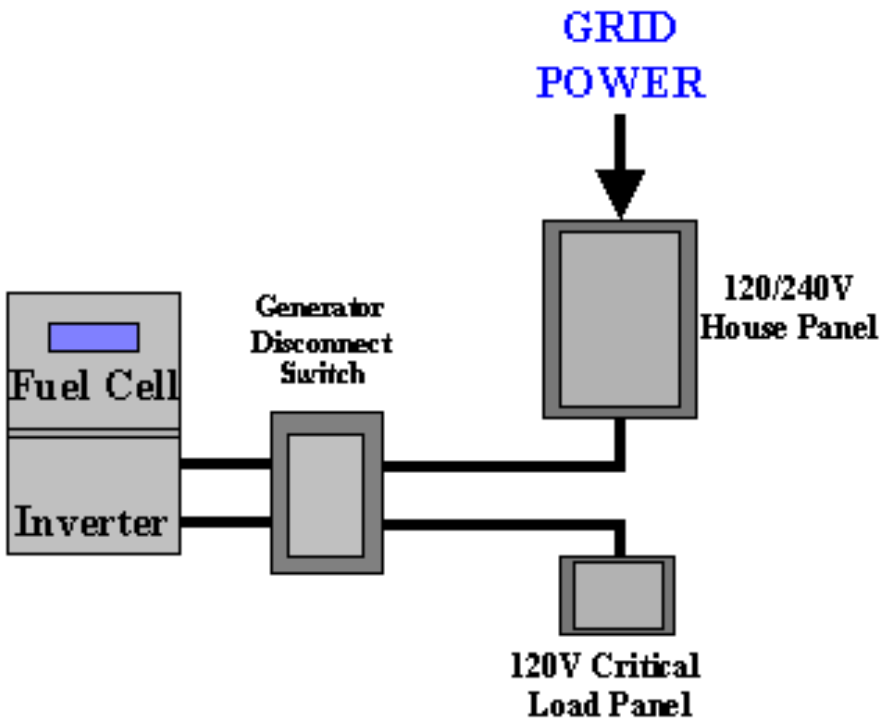


- System protects itself (can't over heat/cool)
- Overall efficiency upwards of 70%
- Heat rejection through radiator if no CHP is used

Heating / CHP Specifications

Power Setpoint	Thermal Energy
2.5 KWe	13,660 BTU/h
4 KWe	25,614 BTU/h
5 KWe	30,736 BTU/hr

INSTALLATION CONFIGURATION - STANDBY



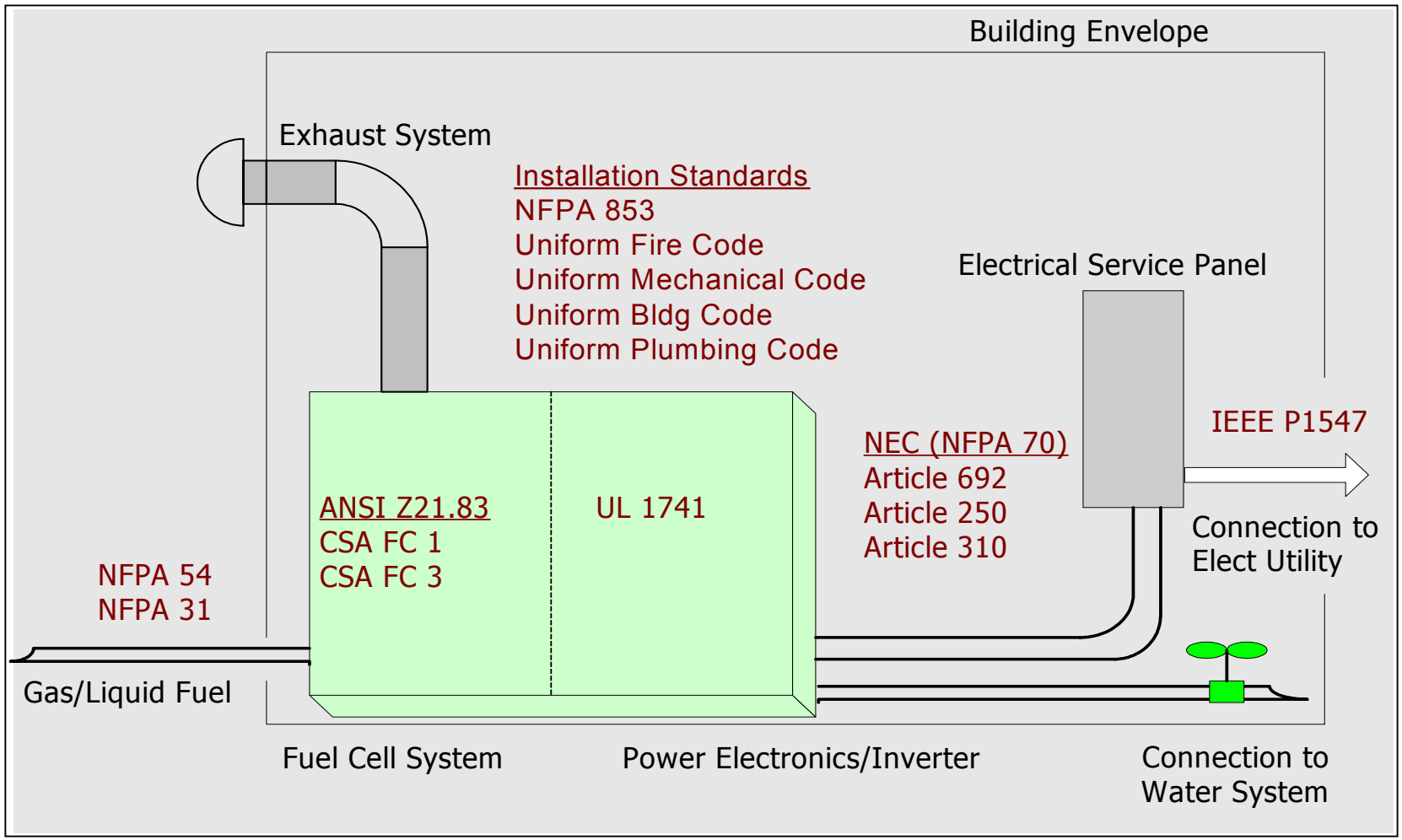
- **Inverter Technology**
  - Output matches grid voltage and frequency
  - Automatic disconnect from grid when abnormal conditions exist
- **Standby**
  - Critical loads supplied when grid is down
  - Automatic transfer prevents interruption

INSTALLATION STANDARDS

- Fire Safety (Fire Marshal) Considerations
  - System Location
    - w/respect to occupied spaces
    - w/respect to windows and entry points
  - Spills and secondary containment
  - Fuel Shutoff - Interlocks
- NFPA 31 - Installation of Oil-Burning Equipment
- NFPA 54 - National Fuel Gas Code
- NFPA 70 - National Electrical Code, Article 692
- NFPA 853 - Installation of Stationary Fuel Cell Power Plants

INSTALLATION CONFIGURATION -

Interfaces - Codes and Standards



ISSUES & CHALLENGES

- Regulations
  - Local regulations inconsistent
  - Unfamiliar technology brings subjectiveness
- Permitting/Inspections
  - Building permits
  - Air permits
  - Mechanical and Electrical inspections
  - Fire Marshall
- Interconnection
  - Application standardization
  - Certification process vs. individual site permitting
- Cost
  - Unfamiliar technology drives initial installation costs up
  - Smarter material selection (cost vs. ease of installation)
  - Standardize installations to reduce site specific customization

ISSUES & CHALLENGES - Interconnection Regulations

- Utility Rules
  - Over 3000 US Utilities
- State Public Utility Commissions
  - California Rule 21
  - New York Standardized Interconnection Rules
  - Texas Substantive Rules Chapter 25, sections 211 & 212
  - Many others in progress
- Pre-Certification
  - Can significantly reduce the cost and time to interconnect with a utility.
  - Requires existing state process
  - Procedure includes UL listing and CSA certification to ANSI Z21.83

PLUG POWER. PLUG WILL.

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